FEATURES

Climate-Based Descriptive Models of Dengue Fever: The 2002 Epidemic in Colima, Mexico

Gerardo Chowell, Ph.D.
Fabio Sanchez, M.S.

Abstract Dengue is a public health problem on the rise in many tropical regions and affects approximately 100 million people every year worldwide. In this paper, the authors retrospectively assess the association between five climatological variables and dengue incidence using data from the 2002 dengue epidemic in Colima, Mexico. Pluvial precipitation (mm), evaporation (mm), and mean, maximum, and minimum temperatures (°C) were obtained from local meteorological stations. The highest correlation of dengue incidence with maximum temperature was found at a lag of one month, and the highest correlation for evaporation was found at a lag of three months. A multiple-linear-regression model that includes all the climatological variables was correlated with 94 percent of the observed variance. Two simpler linear models with variables significant at the 99 percent confidence level were correlated with 88 percent (Precipitation + Evaporation) and 79 percent (Precipitation + Maximum Temperature) of the observed variance.

Introduction

Dengue is the most significant mosquito-transmitted flavivirus-caused disease in tropical areas around the world, including southeast Asia, India, the Western Pacific, and South America (Morens, Folkers, & Fauci, 2004). It affects approximately 100 million people every year. The exact number of cases is unknown because a large number of cases involve few or no symptoms (Kurane & Takasaki, 2001).

Dengue is transmitted by at least two species of mosquitoes, namely *Aedes aegypti* and *Aedes albopictus*. *Aedes aegypti*, the principal vector, can lay 100 to 200 eggs at once. Female mosquitoes are responsible for the transmission of the virus since males feed primarily on plants and flowers (Scott et al., 1993). The lifetime of a mosquito is approximately 15 to 20 days on average. Most mosquito breeding sites are generated by humans (e.g., old toys, water containers, and tires).

Infected mosquitoes transmit the virus by biting a susceptible host. Four dengue serotypes (Den-1, Den-2, Den-3, and Den-4) coexist in the world (mostly in the tropics) (Gubler & Kuno, 1997). Individuals acquire permanent immunity to each strain that infects them, but there is no evidence of cross-immunity. In humans, the dengue virus produces flulike symptoms for up to 14 days. In severe cases of dengue (dengue hemorrhagic fever), the case fatality ratio ranges from 5 percent for treated cases to 15 percent for untreated cases (Gubler & Kuno, 1997).

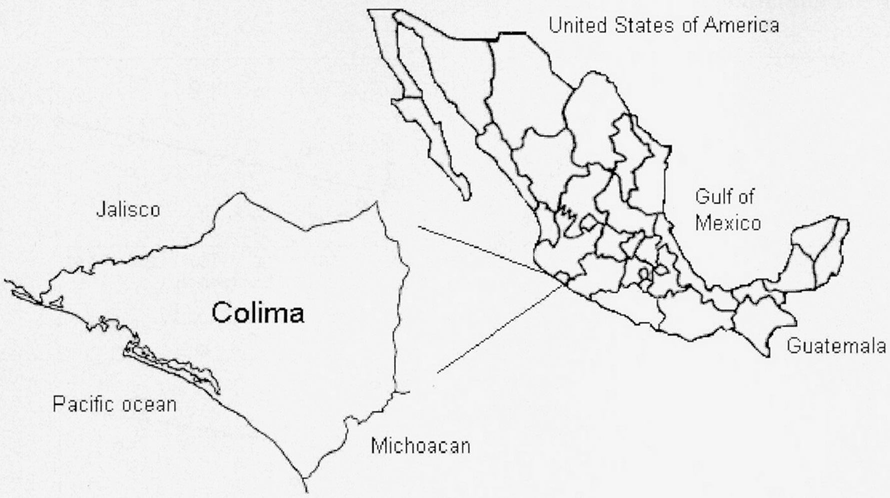
Dengue incidence is becoming endemic in regions where outbreaks used to be sporadic. Hence, control of dengue requires an understanding of the mechanisms and factors that facilitate the invasion, transmission, and persistence of the virus in populations.

Different aspects of the transmission dynamics of dengue are known to depend on climatological conditions; those aspects include the survival and development of the vector *Aedes aegypti* (Jetten & Focks, 1997; Li, Lim, Han, & Fang, 1985; Mourya, Yadav, & Mishra, 2004). The extrinsic incubation period (EIP) and the susceptibility of the mosquito have been observed to depend on temperature (Mourya et al., 2004). Furthermore, seasonal variations in temperature and rainfall have been observed to be correlated with levels of dengue infection, with a higher number of dengue cases associated with higher rainfall and temperature, probably because of increases in mosquito breeding sites during the rainy season (Koopman et al., 1991; Schultz, 1993). A set of general-circulation models of global climate change have made the association between small temperature rises and higher risk of dengue epidemics (Patz, Martens, Focks, & Jetten, 1998).

Factors that facilitate the invasion of the causal agent of dengue are complex and not well understood. In some regions, recurrent epidemics of dengue have been observed, while in other regions only sporadic outbreaks have occurred. The latter situation is the case in the state of Colima, Mexico (Figure 1), where the mosquito

FIGURE 1

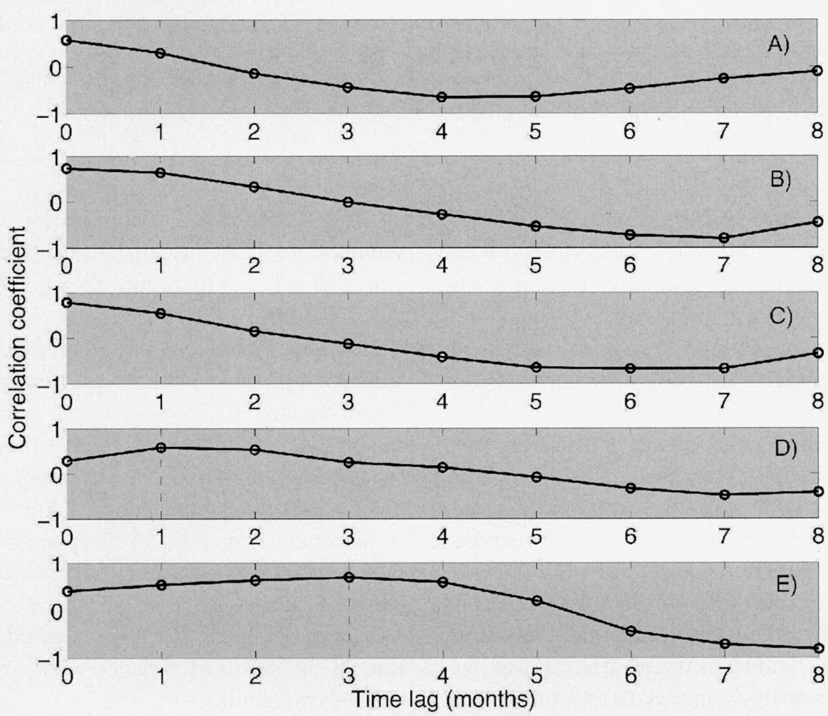
Geographic Location of the State of Colima, Mexico



Map of Mexico with political divisions. The state of Colima is located on the central pacific coast. It has a tropical climate, a surface of 5,455 km^2, a coastline extending 157 km, and a population of approximately 488,028 inhabitants (Instituto Nacional de Estadística, Geografia e Informática, Mexico, 1995).

FIGURE 2

Lagged Cross-Correlation Between Climatological Variables and Dengue Incidence



Lagged cross-correlation of the number of dengue cases with A) precipitation, B) mean temperature, C) minimum temperature, D) maximum temperature, and E) evaporation. While precipitation, temperature, and minimum temperature have their highest correlation with dengue incidence without a lag period (0 lag), maximum temperature and evaporation were most highly correlated with dengue incidence at lags of one and three months, respectively.

population of *Aedes aegypti* is endemic (Espinoza-Gómez, Hernández-Suarez, & Coll-Cardenas, 2001). A significant outbreak occurred in Colima in 1997 (4,910 cases), and the most recent outbreak occurred in 2002 (the outbreak on which this paper is focused), with a total of 2,379 cases confirmed in the laboratory (no cases were reported in 2001) (Espinoza-Gómez, Hernández-Suarez, Rendón-Ramírez, Carrillo-Alvarez, & Flores-González, 2003). Several explanations are possible for the re-emergence of dengue in regions where it had been absent for a prolonged period of time. Possible explanations include the immigration of people infected with a new strain of the virus to which the population is susceptible to, loss of immunity of the population through births and migration, and the invasion of a new strain of the virus from local natural reservoirs as a result of environmental changes.

For this paper, the authors analyzed the correlation between dengue incidence during the 2002 outbreak in Colima, Mexico, and climatological variables. Using cross-correlation analysis, they explored lagged effects of climatological variables on the number of dengue cases observed, and they constructed simple regression models to describe the time course of the epidemic. The study showed that climatological variables were able to explain a high percentage of the observed variance in the time series of dengue infection.

Materials and Methods

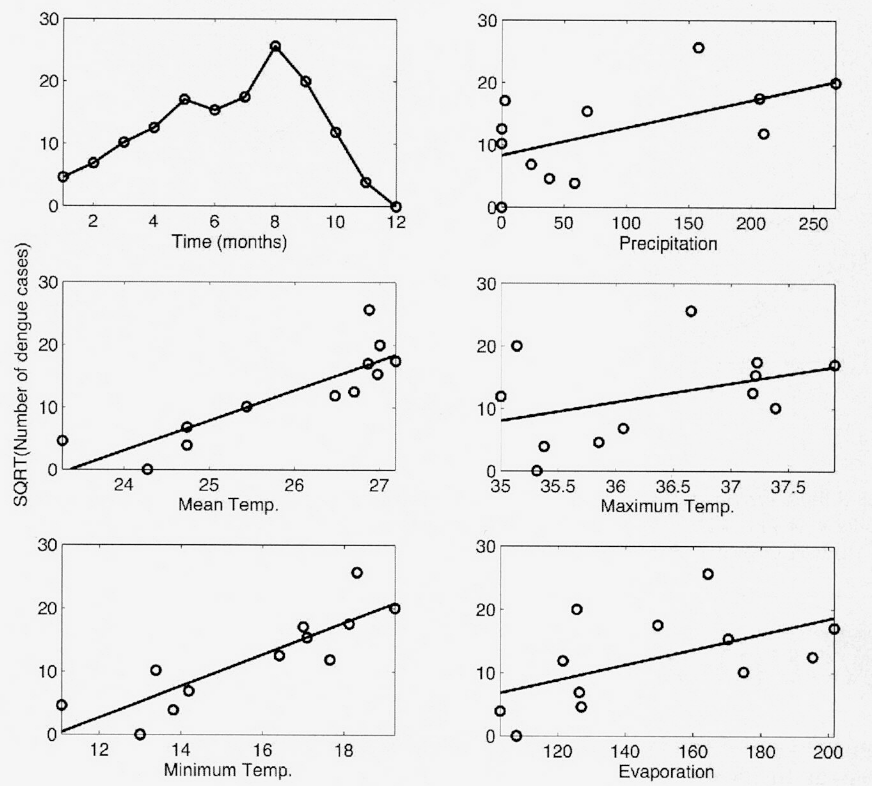
The authors used the monthly number of dengue cases confirmed in the laboratory and reported to the Secretariat of Public Health in the state of Colima, Mexico, during the epidemic that developed in Colima from January through December of 2002. Monthly incidence data reduce some of the variability due to the life cycle of the vector and the time from infection to the presentation of clinical symptoms (incubation period) (Depradine & Lovell, 2004). The state of Colima is located on the central pacific coast, and it has a tropical climate with a mean temperature of 23.2°C, a surface of 5,455 km^2, a coastline extending 157 km, and a population of approximately 488,028 inhabitants (89 inhabitants/km^2) (Instituto Nacional de Estadística, Geografia e Informática, 2000). The geography of Colima covers a range of features, from coastal areas to valleys and volcanic highlands.

The authors considered the correlation of dengue incidence with the following climatological variables: precipitation (mm), mean temperature (°C), maximum temperature, minimum temperature, and evaporation (mm). The data were collected from eight local meteorological offices distributed in the state of Colima, Mexico. The authors used the average of the climatological variables obtained from the meteorological offices. They also carried out a lagged cross-correlation analysis to study lagged effects of the climatological variables on dengue incidence (Depradine et al., 2004; Keating, 2001). For the lagged cross-correlation analysis, the authors used climatological data for the years 2001 and 2002 to adjust the time series of the climatological variables for lag effects on dengue incidence. The possibility that climatological variables have a lagged effect on dengue incidence can be explained as a result of the time it takes for mosquito larva to develop to adult stages, the time it takes infected mosquitoes to become infectious, and the time it takes for infection of a host to lead to clinical symptoms and diagnosis (Depradine et al., 2004; Keating, 2001). Therefore, questions of interest include whether such lags can be recovered from lagged cross-correlation analysis of dengue incidence data and whether all the climatological variables have lagged effects.

The authors also carried out an univariate regression analysis on each of the variables to study the amount of explained variance from each variable in the absence of the other climatological variables. They then performed multiple linear regression (Neter & Wasserman, 1974) using as predictors the five climatological variables mentioned above and simple regression models with predictors significant at the 99 percent significance level.

FIGURE 3

Univariate Regression Analysis of the Number of Dengue Cases Against Each of the Climatological Variables



The time series of the monthly dengue incidence for the 2002 dengue epidemic in Colima, Mexico, and the dengue incidence as a function of the climatological variables: precipitation (mm), mean temperature (°C), maximum temperature, minimum temperature, and evaporation (mm). The square root transformation (SQRT) was applied to the dengue incidence data to stabilize the variance and linearize curvilinear relationships with the climatological variables.

Results

The authors analyzed the correlations between the climatological variables and the time series of dengue incidence. The climatological variables with the highest correlation coefficients were the minimum temperature (r = .79), mean temperature (r = .74), and precipitation (r = .57), followed by evaporation (r = .41) and maximum temperature (r = .29). As mentioned in the previous section, it is of interest to assess the possibility of lagged effects of these climatological variables on dengue incidence. The authors found that for maximum temperature, the highest correlation coefficient for the time series of dengue cases occurred at a lag of one month, while evaporation (mm) was most correlated with dengue incidence at a lag of three months (Figure 2). Precipitation, mean temperature, and minimum temperature were found to be most correlated with dengue incidence without any lag periods.

For the linear-regression analysis, the authors applied the square root transformation (SQRT) to the dengue incidence data to stabilize the variance with increasing numbers of dengue cases and to linearize curvilinear relationships with the corresponding climatological variables. The authors conducted a univariate linear regression analysis on each of the climatological variables available (Figure 3) without taking into consideration the effects of lag period in the impact these variables had on dengue incidence. The minimum-temperature variable gave the maximum explained variance (75 percent), followed by mean temperature (74 percent), precipitation (34 percent), evaporation (30 percent), and maximum temperature (17 percent). A multiple-linear-regression analysis of all the climatological variables resulted in the following model:

SQRT(Dengue incidence) = 25.54 + 0.04 (Precipitation) – 7.92 (Mean Temp.) + 2.62 (Maximum Temp.) + 4.46 (Minimum Temp.) + 0.15 (Evaporation),

which explains 94 percent of the observed variance with p-value = .001 (Figure 4).

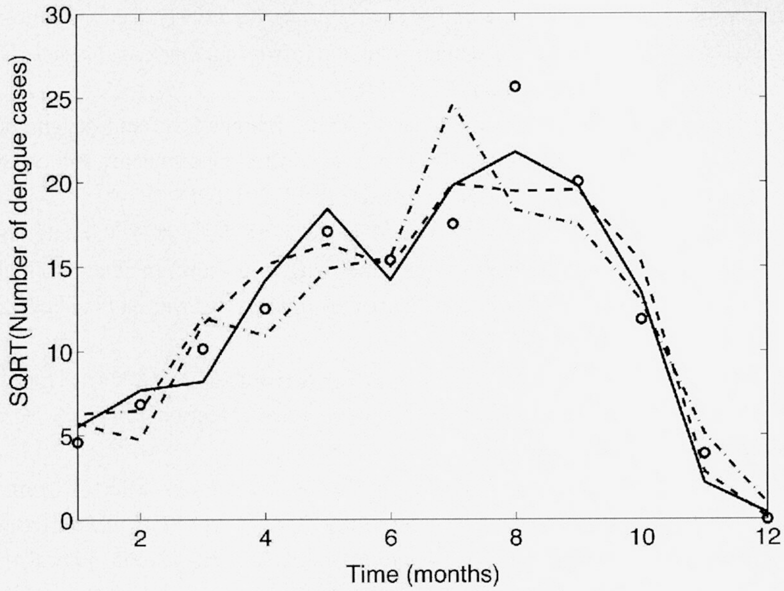
A simpler model, which captured 88 percent of the observed variance with p-value <.001, is as follows:

SQRT(Dengue incidence) = –18.42 + 0.06 (Precipitation) + 0.17 (Evaporation),

where both predictor variables are significant at the 99 percent confidence level (Figure 4).

FIGURE 4

Multiple-Linear-Regression Models for Dengue Incidence Based on Climatological Data



The epidemic data are indicated by circles, the solid line represents the full model fit with the five climatological variables included, the dashed line shows the model fit with precipitation and evaporation included (both significant at the 99 percent level), and the dash-dot line shows the model fit with precipitation and maximum temperature as predictors (both significant at the 99 percent level).

Another simple model, which captured 79 percent of the observed variance with p-value <.001, is given by the following:

SQRT(Dengue incidence) = –187.28 + 0.07 (Precipitation) + 5.33 (Maximum Temp.),

with both predictors significant at the 99 percent confidence level (Figure 4).

Adjusting the time series of maximum temperature and evaporation for the lags at which their respective maximum correlation occurred did not improve the percentage of variance explained by the models given above. A model with such lag adjustment that includes all the climatological variables explains only 86 percent of the observed variance.

Discussion

The authors conducted a retrospective assessment of five climatological variables as predictors of dengue incidence using data from the 2002 dengue epidemic in Colima, Mexico. Climatological variables were found to be significantly correlated with the number of dengue cases. While precipitation, mean temperature, and minimum temperature had their highest correlation with dengue incidence without a lag period, maximum temperature and evaporation were most correlated to dengue incidence at lags of one and three months, respectively (Figure 2). In Puerto Rico, Keating (2001) found the highest correlation between mean temperature (the only climatological variable considered in that study) and dengue incidence at a lag period of three months. In the small Caribbean island of Barbados, Depradine and coauthors (2004) reported different lag periods having highest correlation with dengue incidence. They found a six-week lag for vapor pressure, a seven-week lag for precipitation, a 12-week lag for minimum temperature, and a 16-week lag for maximum temperature. Unfortunately, for the study reported here, the authors had data with a temporal component only in months. Higher-resolution data could allow more accurate lag periods to be estimated.

The authors' simple linear-regression models based on climatological variables were able to describe a high percentage of the observed variance in the time series of dengue incidence (Figure 4). The significant positive correlation of temperature and rainfall with dengue incidence has been reported in other studies (Jetten et al., 1997; Koopman et al., 1991; Li et al., 1985; Mourya et al., 2004; Schultz, 1993). Temperature promotes mosquito larva development, expands the geographic range of the vector, increases the biting rate, and shortens the extrinsic incubation period (Keating, 2001). The results of the study reported here indicate the importance of incorporating climatological data into mechanistic models of dengue transmission when such data are available. That is, the combination of mechanistic and descriptive models could significantly increase the prediction capabilities of models for the transmission dynamics of dengue (Focks, Daniels, Haile, & Keesling, 1995).

In Colima, Mexico, only sporadic outbreaks of dengue have occurred, with continuous low levels of transmission often undetected by traditional public health surveillance (Espinoza-Gómez et al., 2001). Therefore, many other factors must play a role in the development of dengue epidemics. Mosquito density is one variable that could be incorporated into descriptive models of dengue transmission. Estimates of mosquito density have been obtained with mosquito larva indices (Gubler & Kuno, 1997). They could also be obtained more directly through use of CDC backpack aspirator collectors to measure the number of female mosquitoes resting in houses (Harrington et al. 2005). Other factors that could be assessed as predictors of dengue transmission are the intensity of public health interventions: controlling the vector population via larvaciding programs, spraying of insecticides, and efforts to educate the population on how to avoid dengue infections.

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Corresponding Author: Gerardo Chowell, Director's Postdoctoral Fellow, Los Alamos National Laboratory, Mathematical Modeling and Analysis & Statistical Science, MS-B284, Los Alamos, NM 87545. E-mail: chowell@lanl.gov.

References on page 44

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